APPLICATION OF LIGHTNING DETECTION AND WARNING SYSTEMS WITHIN THE EXPLOSIVES AND BLASTING ENVIRONMENT

Mr. William C. Geitz
Atmospheric Research Systems, Inc.
Palm Bay, Florida 32905, USA

Mr. Jack McGuinness
Naval Surface Warfare Center
Dahlgren, Virginia 22448-5000

ABSTRACT

Lightning has always posed a serious threat to operations involving explosives, especially within the DOD and commercial mining and construction industries. In recent years, technological advancements in communications systems and microprocessors have significantly improved the accuracy and efficiency of lightning detection and warning systems and instrumentation. These advancements have also increased the availability of highly reliable, accurate and affordable systems for use in receiving, processing and displaying realtime lightning information and data from warning instrumentation.

Access to these systems, which detect the presence of, or potential for, cloud-to-ground and a varying percentage of cloud stroke lightning, is exposing personnel to one of the most complex elements of atmospheric physics. Armed with this "scientific data", supervisors and managers are expected to make the right decision all of the time, decisions that will have a significant impact on personnel safety, productivity, and the organization's material resources. It is a fact of life that the data they are dealing with is not perfect, can be misinterpreted, and in many cases, can be unwittingly viewed as a false report. Such factors will not only reduce the effectiveness of the system in the every day environment, but also, significantly undermine user confidence which could slow response/reaction to future warnings.

The intent of this paper is to; (1) provide the reader with a basic understanding of thunderstorm/lightning meteorology, (2) review various technologies used in the detection and advance warning of lightning events; (3) address lightning effects on cables; (4) discuss methods and procedures, along with information gained by various activities who employ either detection or advance warning technology, or both, within their daily operations. Access to such information will provide current and potential users with additional insight on these issues, and hopefully, stimulate new ideas on ways such systems can be used to improve the explosives safety environment without compromising operational readiness.

1.0 Introduction

Since the last seminar in St. Louis, Missouri in 1990, there has been a significant increase in the number of organizations utilizing realtime lightning data and/or advance warning, such as Electric Field Mills (EFM), instruments to support operations and safety needs within the explosives environment.

While a significant number of commercial users has evolved, such as Amax Coal Company, Northrup, Rockwell International, and Lockheed Missiles and Space, an equally significant number of users within the Department of Defense (DOD) has also taken place. The system configuration at these activities varies between employment of only realtime detection and tracking systems, or integration with, or stand alone operation of, EFM's.

Some of the activities that utilize only realtime systems include, Redstone Arsenal, NTC Orlando, Maxwell AFB and NAS Memphis. While those integrating such data with EFM outputs include, POMFLANT, NSWC White Oak, NSWC Yorktown, and NAS Jacksonville. In some cases, there are locations that only use EFMs, such as Naval activities in Orlando, Florida, Indian Head, Maryland and Silverdale Washington.

The purpose of this paper is to provide the reader with a refresher on thunderstorm/lightning meteorology, lightning warning and detection instruments and systems, and information gained and procedures used by various activities who employ either detection or EFM technology, or both, within their daily operations. Access to such information, will provide current and potential users additional insight and stimulate new ideas on ways such systems can be used to improve the explosives safety environment, without compromising operational readiness.

2.0 Understanding Thunderstorms and Lightning

Before discussing the application of detection and warning systems, it is important that the reader gain a basic understanding of, and respect for, lightning phenomena and the threat it poses. The information below, while somewhat condensed, is intended to provide a different perspective of thunderstorms and expose the reader to new theories on thunderstorms and lightning.

While thunderstorms are considered to be the most spectacular weather phenomena, lightning by far is the most dangerous. Traveling at the speed of light, the energy of a lightning discharge can reach a magnitude of well over 200,000 amps or several tens of millions of volts. More people are killed annually by lightning than by tornadoes, hurricanes or floods.

2.1 Types of Thunderstorms

There are two types of thunderstorms, synoptic and air mass. Synoptic thunderstorms are those which are

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generated by major weather systems such as fronts, low pressure systems, and hurricanes. On the other hand, the air mass variety appear as singular or groups (clusters) of cells which form during the summer throughout the United States.

2.1.1 Synoptic Thunderstorms

These thunderstorms usually involve a broad area and demonstrate some consistency as to their movement and intensity. Some may be embedded in large areas of cloudiness, as with a warm front, while others will form a distinct line when associated with cold fronts. Typically, the most severe form of thunderstorm will frequently be found in a squall line, which is spawned by a fast moving cold front. These storms have been known to move at ground speeds greater than 60 mph and, in some cases, their tops may extend more than 50,000 feet into the atmosphere. It is not uncommon for these storms to produce large hail, high winds, tornadoes and flooding.

One advantage when dealing with synoptic activity is that the frequency and intensity of the storms is predicted with a high level of accuracy. Thus, adequate warning is usually provided in advance so people can take action to reduce potential for damage, or anticipate unavoidable damage.

2.1.2 Air Mass Thunderstorms

As previously noted, these storms are normally generated by the heat of the day and involve either individual or groups of cells. When addressing a group of cells, the most common types are clusters and lines. A good example of such activity is the line of thunderstorms that form along the Ohio River Valley or over the Piedmont area of the Carolinas during the Summer months.

These storms are highly predictable, especially during the Summer, when the only day to day change in patterns is storm movement, or the location where they may initially form. There are times when conditions over a certain area are enhanced by converging wind fields or synoptic systems in the upper atmosphere. When this occurs, storm activity tends to increase and involves a larger area. The biggest problem associated with these storms is that they can develop quickly and thus, create a first strike hazard with no advance warning of such an event. Therefore, it is fair to state that air mass thunderstorms represent the most serious threat to the explosives environment.

2.2 Thunderstorm Origins

A typical thunderstorm involves three stages; (1) Cumulus, 2) Mature, and 3) Dissipation. In some cases, a fourth stage, called the redevelopment stage, may also occur in various situations. The life cycle of a typical thunderstorm will vary between 1 and 2 hours. For convenience, the term "cell" is used to address individual thunderstorms.

For a cell to form, three elements are necessary; (1) moisture, (2) a lifting action, and (3) hygroscopic nuclei. Sources of moisture may be large bodies of water such as oceans, lakes, rivers, or other local sources, such as ponds and streams. In most cases, the lifting action is supplied by warm air as it rises from the earth's surface. However, other natural actions such as wind flowing up mountain slopes, or sea/land breeze regimes can also produce sufficient lift. Hydroscopic nuclei serves as a host upon which water vapor will adhere when it undergoes the process of condensation. The type of nuclei varies geographically and can include coal dust, sand, salt crystals and various forms of industrial pollutants. It is important to note that a delicate balance of these elements must be sustained during the cell's development. If any one element's influence is reduced, or becomes dominant, then the cell will normally not evolve into a thunderstorm.

2.2.1 Cumulus Stage

This stage is recognizable by the formation of puffy white clouds that form into a basic cell. The cell feeds on the warm moist air from below, and as it builds into the atmosphere, draws additional moisture and heat from the surrounding air. During this stage, all currents within the cell are upward and during the latter phases, downdrafts begin to form in the upper portion of the cell. Occasional intracloud lightning may occur near the end of this stage.

2.2.2 Mature Stage

During this stage, well defined downdraft and updraft patterns are established within the cell. As the cell builds further into the atmosphere, it will normally encounter a uniform wind field that pushes some of the associated cloud mass away from the main cell. This mass is commonly called an anvil. The altitude of the anvil's base may vary from 25,000-30,000 feet above ground level. In addition, as the cell approaches full maturity, its appearance will take on a more ominous character as the moisture content and lightning activity increases. A cell is fully matured when precipitation falls from the base and reaches the earth. This event is preceded by a release of cold air from the base of the cloud that takes place in the form of a downdraft.

As this downdraft travels downward, it comes in contact with the earth and on impact, moves horizontally outward in all directions. This event is commonly called a "first gust front". The horizontal extent of this front is greatest along the cell's axis of movement. It is not uncommon for the windfield to extend 15 miles ahead of the cell and more than 5 miles in other directions. Winds in excess of 100 knots have been recorded in more severe versions. During this phase, a significant increase in lightning activity takes place. When considering the sequence of events we have discussed to this point, it is obvious that the on-set of the first gust front is an environmental alarm that alerts us to approaching danger.

2.2.3 Dissipation Stage

During this stage, all motion within the cell is downward. Lightning is still active during the early part of this stage; however, as the rain subsides, the lightning tapers off and the wind gradually abates. Many people will disagree with such a statement, because at one time or another they have encountered situations where the wind, rain and lightning have persisted for many hours from what appeared to be one cell, or area. In a sense they are correct because such a scenario can and does occur, especially with synoptic thunderstorms. To better understand the cause of such conditions, it is important that a fourth stage of the thunderstorm process, the redevelopment cycle, be recognized.

2.2.4 Redevelopment Cycle

As the cold air within the first gust front travels outward from the cell, it is once again warmed by the earth's surface and the surrounding air, and obtains moisture from the atmosphere and other sources. The air is slowly modified and begins to rise and turn in a counterclockwise motion. This action results in a new thunderstorm cell which may evolve into a thunderstorm as the parent cell decays.

This cycle is not uncommon in an air mass situation, especially if a line or cluster is involved, or a very unstable feature such as an upper level trough is present. Personnel should be sensitive to the re-appearance of indications common to the cumulus and mature stages to recognize this event, since most of the time the associated cloud mass is disguised by residual clouds generated by the parent cell.

2.3 Thunderstorm Categories

There are only two categories of thunderstorms, normal and severe. By definition, a severe storm must produce surface wind speeds of 50 knots or greater or hail, if present, that is 3/4 inch in diameter or greater. If conditions are less than these, the storm is viewed as a normal thunderstorm. In addition, under current rules, the type of lightning or its frequency are not used in classifying storm severity.

2.4 The Lightning Profile

The atmosphere in its normal state has a positive charge, while the earth's is negative. As a thunderstorm enters the latter portion of the cumulus stage, the on-set of down drafts within the upper portion of the cloud induces a mixture of charges within the cell. As the cell builds through the freezing level and enters the early part of the mature stage, a discharge between the positive charged region in the cloud base and the negatively charged region above it takes place. This event frees electrons in the negative region which were previously immobilized by attachment to water/ice particles being carried downward within the cloud.

The freed electrons overrun the positive region along the base of the cloud, neutralizing its small positive charge, then continue their trip toward the ground, which takes 20 milliseconds. The vehicle for moving the negative charge to earth is the stepped leader, which moves from the cloud to the ground in rapid luminous steps each of which are 150 feet in length. Each leader step occurs in less than a microsecond and the time between steps is about 50 microseconds.

When the stepped leader is near ground, its large negative charge induces large amounts of positive charge beneath it on the earth and objects projecting above the earth's surface. Since opposite charges attract each other, the positive charge attempts to join the negative charge and in doing so, initiates upward going discharges. One of these discharges contacts the downward-moving leader and thereby determines the lightning strike point. When the leader initially touches ground, electrons flow to ground from the channel base and as the return stroke moves upward, large numbers of electrons flow at greater and greater heights. It is this return stroke that produces the bright visible channel.

The human eye is not fast enough to see the propagation of the return stroke or the stepped leader preceding it. To an observer, it appears that all points on the channel become bright simultaneously. The total discharge takes place in 0.5 sec., and is called a flash. Each component discharge called a "stroke", is measured in tenths of milliseconds. Usually, a flash contains 3 or 4 strokes. Often lightning appears to flicker. In such cases, the eye is detecting the individual strokes which make up the flash. Contrary to popular belief, strokes within a flash may not always originate at the point where the original discharge takes place. Parameters (distance and time) used to qualify such events varies from 3 km and 180 milliseconds, to 10 Km and 500 milliseconds, Casper [1]. Figure-1 provides an overview of such events.

2.4.1 Types of Lightning

Currently, there are only four recognized types of lightning; (1) intracloud, (2) cloud to cloud, (3) cloud to air and, (4) cloud to ground (CG). In many cases, the first three are grouped into one term "cloud strokes". The remainder of this section will primarily deal with CG lightning.

2.4.2 Bolts From the Blue

This is the most dangerous form of CG lightning, in that it will affect people who at the time of the event, think they are safe by virtue of their distance from the thunderstorm cell. In some cases, CG lightning has affected an area that is under sunny skies, and thus the term "Bolt from the Blue" was born. In most cases, the anvil that spreads from the upper portion of the thunderstorm is the source of this type of lightning. Within the anvil the typical electrical pattern is reversed in that a positive charge extends over a section of earth where the ground is still in a state of negative charge. When considering the distance from the base of the anvil to the ground, it is not unusual to see strong discharges associated with this type of lightning. There have been reports of these lightning strokes occurring up to 30 miles from the main cell, and producing currents in excess of 150 kiloamps.

3.0 Lightning Effects on Overhead and Buried Cable

Facilities manufacturing or using explosives may suffer from lightning effects even though the lightning may be several miles away and within a cloud. Induced electrical and magnetic effects from such lightning in cables can cause large voltages [2]. These over-voltages can cause many problems such as premature ignition of explosive devices used in blasting operations. Excessive sparking between cables may also cause detonation of gasses in explosives manufacturing plants. Adequate bonding and surge suppression may help to reduce these effects, but direct strikes will almost always cause some sparking.

The major sources of lightning surges in conductors are due to:

a) Ground potentials caused by nearby lightning strokes.
b) Induced effects caused by lightning current flowing on a shield.
c) Direct strokes to a wire.
d) Side-flashes to the conductor from a nearby strike.
e) A straight conductor acting as a electrical field change antenna for lightning effects.
f) A looped conductor acting as a magnetic field antenna for lightning effects.

Burying the cable does not remove lightning effects, as the cable is then an ideal ground path for the current. The lightning current may side-flash several meters to the conductor under the ground, where the distance is primarily a function of solid resistivity and the resistance of the conductor to ground.

The largest lightning voltage recorded on a transmission line reached a peak value of 5 million volts in less than two microseconds.

The resulting oscilloscope recording is shown in Figure 3 and the stroke occurred some 4 miles up the line. It is suggested that closer to the strike point, the current rate was probably of the order of 10 million volts per microsecond.

Residential 120V AC lines are found to experience peak lightning associated voltages of up to 6 kV and internal switching transients up to 3 kV. The transients will be oscillatory in nature with a fundamental frequency from a few tens of kilohertz to several megahertz with components ranging into hundreds of megahertz. They will last from 100 nanoseconds to 100 microseconds and be clamped within a few cycles. Good grounding and bonding may reduce the transients significantly.

Intracloud lightning causes a considerable number of induced effects on cables of several thousand volts and several hundred amps even though the separation distance of cable to discharge may be several miles. The main reason for such an effect is that the power, telephone, or data cable acts as an antenna. Shorter cable give rise to larger surges due to reflections at the cable ends.

Nearby cloud or air discharges, particularly if the stroke channel is directly above and parallel to a line, may cause appreciable voltages in the line. A value of 10 kV/km for an earth resistivity of 1,000 ohms m. has been calculated (Boyce, 1962). Thus, nearby cloud discharges will cause protector operation and induce substantial currents in lines. It is however, difficult to obtain data on the effects of such discharges since their location and orientation are not readily determined.

In the case of lightning strokes to ground more than about 30 kilometers from a line, the radiation component of the field is predominant. At distances exceeding several hundred kilometers, the induced voltage in the line comprises a train of waves caused by successive reflections of the radiated pulse from the ionosphere and earth. The peak voltages do not exceed a few tens of volts, and at most, they may cause some noise in unbalanced lines. Ground strokes further than 3 to 5 kilometers from a line normally induce less than a kilovolt in lines of any appreciable length, although higher voltages will occur on short, well-insulated lines. Again, the currents to ground through terminal protectors are small.

Strokes to ground at distances of between about 25 and 3,000 meters will generally induce more than 1,000 volts in overhead lines, and these, together with direct strokes to the line, are of principal importance. The maximum voltage is induced at or near a point on the line opposite the lightning stroke. A surge is propagated along the conductor in both directions, and repeated reflections occur from both ends of the line, resulting in surge durations up to several milliseconds. Both the time to crest and the time to half-value of initial surge increase with distance from the stroke, as may be seen from Figure 4. Some indication of the order of currents in a single horizontal conductor 1,000 meters or more in length above earth with zero resistivity, is given in Figure 5 for various stroke currents and distances from the stroke. The crest currents and not the voltages are given since the current is of greater importance in specifying the characteristics of protectors. On a long line, the crest currents in the traveling waves, before attenuation, will be half of the values in these figures, and the crest voltage will be the product of this current and the surge impedance of the conductor. Heavy discharges nearer than 50 or even 100 meters from the line will cause flashover of the insulators. Hence, the full currents given in Figures 4 & 5 will not always be propagated at both ends of the terminal protectors, and this means there is a voltage between the ends of the line. This voltage is plotted as a function of time in Figure 6. Since the gradient decreases rapidly with distance from the flash, the voltage difference between the ends of the line is determined mainly by the potential at the end nearest to the flash, unless the line is shorter than 300 to 400 meters. The surge impedance of a short line, due to multiple reflections, reduces very rapidly to the terminating impedance, which is normally the resistance of the earth electrode. Since an earth resistivity of 1,000 ohm m. may be considerably exceeded, currents of the order of 5 to 10 kA are possible in short lines--these are much higher than the few hundred amperes in Figure 5.

The various ways in which voltages and currents in paired and coaxial cables are caused by nearby ground flashes depend in a complex manner on several factors. If the lightning current enters a cable at some point along its length, the current will divide into two roughly equal parts on each side of the point of impact. Particularly in high ground-resistivity areas, these surge currents will flow for considerable distances in metal sheaths before being attenuated and dissipated to ground.

These currents cause a voltage drop on the internal surface of the sheath, and this appears as an impulse voltage between the sheath and the conductors. Figure 6 is based on a formula by Sunde. If breakdown occurs, part of the lightning current will flow into the conductors. Since the attenuation of the conductors/sheath circuit is much less than that of the sheath/earth circuit, the voltage between the sheath and the conductors increases with distance from the impact point, and further damage to the cable may occur several kilometers away.

In addition to the foregoing mechanism, high currents are produced in short cable conductors by the differences in the earth potentials at points (such as the ends of branching points), where protectors to earth are fitted in exactly the same way as described for open-wire lines. This occurs even though there has been no breakdown in the cable itself. This effect is more serious than for open-wire lines, since cable conductors are smaller in diameter and are more easily fused than open-wire lines. Large differences in potential between the conductors also occur at various points along a cable which has protectors fitted to some pairs only at branching points.

4.0 Detection and Warning Systems

For the detection and location of CG lightning, there are two proven approaches; 1) magnetic direction finding (MDF) [3] and, [4] time-of-arrival (TOA) [5].

4.0.1. MDF Technology

The MDF technique has been in widespread use since the late 1970s and is based on the relative induced voltages and polarities in an orthogonal loop pair of antennas. While this technology certainly represented a major advancement over the limited capabilities of past systems there are problems with site errors, Pierce [6]. More recent papers indicate that the average accuracy of a MDF network varies from 6-10 Km [7], based on the number of sensors employed and their operating baselines. There are many forms of these "flash detectors" and their accuracy will vary with design and/or the technology employed. Another form of this technology incorporates a stand-along sensor design. These systems lack sufficent accuracy to support reliable application within typical explosives operations. As noted by Wantland and Free [8], such storm trackers "measure the direction of flashes just like the networks, but analyze the waveform shapes of several strikes to estimate storm distances to within a few miles".

4.0.2 TOA Technology

For more than half a century, TOA technology, which is also used in the satellite based Global Positioning System, has by far, been considered to be the most accurate way of fixing the source of an individual spheric. The exceptional accuracy of these systems is made possible through use of accurate interstation timing of less than 1 microsecond. Papers by Bent, [5] and Lyons and Bent [9] describe basic system operations and present examples of data collected by operating TOA networks in the U.S. during the early 1980s. In addition, more recent papers by Casper [10] and independent research by Dr. M.J.G. Janssen [11], and E. Montandon [12] address accuracies of 200-600 meters or better from TOA networks and document the superiority TOA technology has over the antiquated MDF method.

4.0.3 Warning Systems

The most common and reliable technology utilized to provide advance warning of the potential for lightning is the electric field mill. This instrument is designed to constantly measure the intensity of the potential electric field, either negative or positive, between the base of the clouds and the surface of the earth. Once a predetermined alarm threshold is exceeded, the system will activate an audible and/or visual alarm.

The reliability and accuracy of these devices varies from a primary level of measurement, to what can only be defined as gadgets. The price of the latter may vary from $50 to as much as $4,000, while more reliable high resolution EFMs will cost approximately $6,000. Most designs support integration with a PC and/or remote alarm, and provide digital (RS-232) and/or analog outputs.

In the past, there has been serious concern regarding the use of these systems since many view them as being prone to false alarms, thus production orientated people are hesitant to respond to an alarm that is initiated at a preset value someone claims is ideal to optimize system application. The alarm threshold commonly used is 2,000 Volts per meter (Vm). Many scientists feel that when this level of potential is met, conditions are ideal for a lightning event. While some systems may lay claim to a substantial increase in resolution above 5,000 Vm, when such a level has been attained, in most cases any opportunity for a timely response to the threat has been all but lost, and their is a likelyhood that a lightning event has already occurred.

In most cases, the field mill's reputation for false alarms is unfair since most of the time such determinations are based on observations obtained through application of unsound procedures. For example, counting the seconds between the flash and the sound of thunder to determine the distance to the storm is no longer viewed as an acceptable method. Research has shown that in many cases, up to 40% of the thunder associated with lightning is not heard by the people who observe the event. This is usually caused by, atmospheric abnormalities such as sound focusing and distortion induced by the wind-field.

Figure 2 shows a comparison between real time lightning data and a field mill. The field mill data shows an electric field in excess of 2,000 Vm occurring within a 10 mile range (Point 1) and at least 15 minutes advance warning for a stroke that occurred at a distance of less than 5 miles (Point 2). Of particular interest are the field changes that occur when lightning strokes, both cloud and ground, take place nearby, as can be seen at points 1 and 2, and between points 3 and 4.

5.0 Data Timeliness and Display

Within this section we will discuss the impact data timeliness has on the user, and the types of displays most commonly used to view data.

5.1 Data Timeliness

With regard to time, there are basically two types of data, realtime and other than realtime (aged). Realtime lightning data will normally be delivered and displayed within a reasonable time after the event. In most cases, if the data is received within 1-minute of the actual event it is considered to be realtime. Aged data (other than realtime) may be received with an induced delay, be buffered for a period of time then sent at established time slots, or combined with other data from radar and satellites.

5.1.1 Realtime Data

Realtime data provides an overview of what is going on at the present time. When integrated with realtime data previously received, a reasonable interpretation of the scope of the activity, its projected movement and closest point of approach or time of arrival at the site can be determined with a reasonable level of credibility. Thus the user can anticipate when the threat will occur, and in some applications, what action can be taken to reduce damage to facilities and disruption of operations.

Users of realtime data must always keep in mind that various elements and processes within the atmosphere can produce significant variations in existing patterns. The thunderstorm cycle, local topography or the time of day when a system passes could produce storm intensities that are less, or more intense than, what was originally viewed.

5.1.2 Aged Data

Aged data is normally intended to provide users with a broad picture of what has already occurred within a specific time-window. In many cases subject data is meshed with similar information such as radar data and satellite imagery. It must be remembered that as the age of the data increases, there is a significant decrease in its application value. This data form is not recommended if lightning sensitive operations are conducted on a routine basis and the site experiences more than 5 thunderstorm days per year.

5.2 Data Displays

With the advent of advanced video graphics and high speed and compact processors, industry has been able to be very response to varied requirements for ways to display data, along with supporting background graphics. In general, there are two basic categories of displays: (1) Pavlovian; and, (2) hands-on.

5.2.1 Pavlovian Display

This type of display is normally connected to an on-site sensor. Basically, the function of the display involves flashing lights, bells and whistles scenario that is designed to generate a response of sorts from the user. Type of displays include red lights, flashing lights, alarms, or one of the most common, a computer based system that displays a pie shaped circle that will change color, based on the number of flashes/strokes detected within a particular slice. These displays can be effective to some extent as long as the function of the system operator is to initiate a response and the alarm thresholds and system controls are accessible so that changes can be implemented whenever changes in the activity's mission take place.

Some serious drawbacks of such displays include the inability to determine the storm's direction and speed or its stage of development involved. In addition, many times such systems are advertised as providing the user with storm severity, which is determined by counting the number of flashes that occur within a given timeframe. While this claim may inadvertently by true in some cases, there is no scientific proof to support such a claim, and as stated earlier, lightning frequency is not a consideration when determining storm severity. If it were, surely the National Weather Service recognize such a technique.

The biggest drawback of this type of display is that the user never gets a feel for patterns associated with storm activity, and is placed in a position that any action must be tied to the color pattern and/or some form of alarm device, either audio and/or visual, since no reference point is available to quality control the data before responding. This scenario can created problems that will directly impact on productivity, and reduce user confidence in the system over time. For example, follow-up evaluation of alarm actions may later be ruled as false even though only limited supporting data is available, In addition, the system operators may be forced into a position where they must wait for an alarm before any action can be taken.

5.2.2 Hands-On Displays

This type of display is designed to assist the user in monitoring the size, patterns, density and movement of thunderstorm areas. The biggest advantage gained from such an operating profile is that the user can normally gain a feel for the thunderstorm pattern and anticipate future movement and speed of the cell(s) with an adequate level of accuracy.

Naturally, the most important part of any hands-on display system is the software used to operate it. These software packages are usually menu driven, user friendly and include a basic screen display that is either generic to system users, or tailored to specifically meet both generic and unique needs. Many packages will also include added features that the operator can use to enhance and/or further manipulate the displayed data. Special purpose operating features that are common to most systems include zoom, time lapse and data looping.

Some of the more sophisticated software packages may include user programmable features that include alarm areas, movable windows, integration of electric field mills, predefined displays, alternate map setups, range and bearing determination, a cycle graphic, access to stroke details on command, and greater control of map and display features, titles and time. All of these elements further enhance the potential for accurate/effective interpretation of the data base by layman.

Graphic displays have become very popular because they usually employ a background map which depicts various landmarks, such as roads, towns, and the user's facility. The ability to view data in this form further enhances the users ability to "feel" the storm and maintain proper orientation when viewing the lightning activity as it moves closer to the user's facility.

It is important to note that most hands-on displays include a user controlled Pavlovian profile. The Pavlovian application differs when used with these displays in that its purpose is to attract the attention of the user to the system to effect data review and manipulation, rather than cause a direct response. In addition, in most cases, the system operator has extended control over alarm thresholds, the area they affect, and the type(s) of alarms employed.

6.0 Data Manipulation, Application, and Integration

This section will address the three issues stated, in a combined form, with respect to lightning detection systems and advance warning instrumentation. To help the reader gain a perspective on the various types of systems and how they may integrate with each other, Figure 8 is provided. This drawing provides an overview of a fully automated system designed for the Greater Orlando Airport Authority (GOAA). The system depicted has been installed and is currently undergoing a ninety evaluation process, the results of which will be used to determine what settings and thresholds will be used in the standard operating profile.

6.1 Detection Systems

This section will address the use of data from stand-alone systems (on-site) and data that is received from a network of sensors like those employed by the Navy in their Lightning Detection and Tracking System Networks. It cannot be overly stressed that these types of systems rely on the fact that lightning has or is occurring. Use of a detection system will not alert the user to the presence of a cell developing overhead or the threat posed by an anvil, either of which could produce a first strike at the facility. Thus, while the potential for a first stroke event to take place at a specific time and place, is slim, the decision as to whether such a risk is governed to a great extent by the nature of the operations being conducted.

For example, when conditions appear to be threatening at a training facility such as NTC Orlando, the decision, in the absence of any lightning, to move personnel indoors is based more on not having the troops get drenched, then it is on the danger lightning presents. On the other hand, if munitions are being handled, a response under similar circumstances would be borne out of concern that there is a good chance for that lightning will occur, based on the ominous appearance of the clouds.

6.1.1 Stand-Alone Systems

These systems are basically flash detectors for the most part, and their design may be as simple as a black box with a simple antenna design, to a platform mounted sensor in an open field. The more basic detectors include an alarm system within their design that is rather simple and to the point. Most detectors use an averaging method, and if designed to measure an electro-magnetic signal, are subject to local interference, site-errors and other elements that could further degrade the limited accuracy of such systems. Some include a capability to be integrated with a PC, on which various data is displayed, or a chart recorder.

For the most part, depending on the technology used, such sensors do not offer the level of accuracy sustained by networks, In addition to the lack of a reasonable level of accuracy, many of these systems, by virtue of their display profile, are Pavlovian in nature and give little room for the user to try and evaluate the data to ascertain the storm's direction of movement, its speed, intensity or the existence of a cyclic pattern.

In many applications such sensors have proven to be of some value. However, use of such systems should be limited to small scale operations that are conducted in areas where little or no thunderstorm activity takes place (less than 8 thunderstorms days per year) and only a Pavlovian application would be employed.

6.1.2 Network Data

During the past fifteen months the Department of Commerce (DOC) and NOAA have been conducting a competitive procurement under which they will obtain realtime lightning data for the contiguous 48 states and adjacent coastal areas and boarder areas. Although negotiations continue, a contract is scheduled for award sometime in September, 1992. Within the solicitation, specific note was made of the need for such data in support of ordnance and weapons related operations.

The reason for such interest in network data is obvious in that data provided by sensors designed to function as a network produce the best results with respect to lightning detection and location accuracy. In addition, the data supplied under the contract will employ TOA technology and provide a data base which will reflect individual stroke information.

Personnel who currently utilize this data are able to perform various levels of analysis, even though they are layman, For example, the user is able to ascertain not only the general patterns as they evolve, but also get a feel for the system's movement and its cyclic profile. Armed with this information, the user can make adjustments in schedules, anticipate disruptions during certain periods and, after operations are shut-down or curtailed, determine when conditions are such that a return to limited or full operation is warranted. Experience has shown that use of such data is only limited by the imagination of the user.

In addition to the above, such displays can be setup to work in a Pavlovian profile, and at any time be overridden by a human if need be. The advantage to this capability is that non-technical personnel can be used to monitor the system for alarms that are determined by supervisors and/or managers, then when an alarm is initiated, contact appropriate personnel who will further analyze the data and determine a response will be necessary.

Such systems usually have the capability to injest and display data from advanced warning systems. Typically, the actual Vm levels measured by each EFM are displayed. As discussed below, access to such data and its corrolation with realtime stroke data offer a complete overview of the lightning profile to the system operator.

6.2 Advanced Warning System (Stand-Alone)

As discussed above, there will be situations where overhead development of what appears to be convection activity would have an impact on operations. In many cases, weather patterns such as warm fronts or local convective activity, while intense at times, will not produce thunderstorms. While conditions will be similar to those viewed during activity, vertical development of the activity may be suppressed and therefore only rain will occur.

It is during threatening conditions that do not produce thunderstorms, that an advanced warning system such as an EFM, serves its most useful purpose. The fact that operations continue during conditions which would normally produce a shut-down, can result in substantial savings. Likewise, as a thunderstorm moves away from a site, noting the EFM's return to a stable profile, can facilitate a timely return to normal operations.

In addition to an advanced warning application, some users of EFMs have employed them as lightning detectors. When tied to a digital output or graphic profile, the viewed data can be used to identify the presence of nearby lightning activity (Figure 2), especially cloud strokes. However, it is important to note that with the exception of the on-site response to an exceeded threshold, data from the EFM cannot provide a profile reflecting direction of and speed, or actual location of the cell with respect to the user site.

As we can see, use of EFMs, as a detection system, has its positive and negative points. As with many instruments, initiative on the part of the end-user often produces an added application that in most cases, may be limited in scope. For example, the writer knows of some people who use EFM data to get a feel for static charge during Winter months. While this is case where the instrument is used to monitor conditions that are extremely stable conditions, rather than unstable, the bottom line is that by understanding the strengths and weaknesses of such an application, the end-user can benefit from the additional application. However, personnel should exercise caution when using any instrumentation for an application for which it was not designed. A better method by far, would be to integrate such data with other data bases, producing information that, through correlation, can produce expanded results.

7.0 Conclusions

After careful review of the information provided herein, it is obvious that only through proper planning can a potential user of lightning detection and advance warning systems select the operating profile needed to support their mission. In addition, items such as the level of control exercised by personnel who directly and indirectly use and apply the data, required accuracy, and the need to develop an effective program and system configuration that can meet the demands of existing requirements and will be flexible in responding to future changes in the activity's mission.

REFERENCES

[1] Casper, P.W., Bent, R.B, 1992: Results from the U.S.A. National Lightning Detection and Tracking System for the 1991 Lightning Season.

[2] Horner, F., 1954: Influence of Buried Condictors on Bearings. Wireless Engineer, 30, p. 186, 191.

[3] Krider, E.P., R.C. Noggle, and M.A. Uman, 1976: A Gated Wideband Magnetic Direction Finder for Lightning Return Strokes. J. Appl. Meteor., 15,301-306.

[4] Pierce, E.T., 1982: Spherics and Other Electrical Techniques for Storm Investigations. In, Thunderstorms: A Social, Scientific and Technological Documentary, Vol. 3, E. Kessler, Ed., USDOC, NOAA, U.S. Gov. Printing Office, 135-148.

[5] Bent, R.B., P.W. Casper, T.H. Scheffler, and R. Leep, 1983: A Unique Time-of-Arrival Technique for Accurately Locating Lightning over Large Areas. Reprints, Fifth Symposium on Meteorological Observations and Instrumentation. Toronto, AMS, 505-511.

[6] EPRI Lightning Flashes, Issue No. 1., April 1990, NLDN Subscriber Profile, p.6.

[7] Wantland, W., and J. Free, 1990: Predicting Deadly Lightning. Popular Science, May 1990, p. 89.

[8] Lyons, W.A. and R.B. Bent, 1983: Evaluation of the Time-of-Arrival (TOA) Technique for Real-Time Ground Strike Measurements Using the Lightning Position and Tracking System (LPATS). Preprints, 13th Conf. on Severe Local Storms, AMS, Tulsa, 37-40.

[9] Casper, P.W., March 1990: A Balanced Comparison of Time-of-Arrival vs. Direction Finding Technology for Lightning Ground Stroke Tracking Systems.

[10] Janssen, M.J.G., "The LPATS III System in the Netherlands - Critical Evaluation of the Results" Proc. International Conf. on Lightning and Static Electricity, September, 1989.

[11] Montandon, E., Ahnebrink, T., and R.B. Bent, 1992: Analysis of Lightning Strike Density and Recorded Waveforms by the Swiss Lightning Position and Tracking System.

N	33.281	W	105.524	14:18:07	20-Sep-90	-87	KAmps	
N	36.437	W	106.635	14:18:08	20-Sep-90	+68	KAmps	
N	34.924	W	107.952	14:18:09	20-Sep-90	-16	KAmps	
N	29.299	W	89.490	14:18:22	20-Sep-90	-28	KAmps	
N	29.326	W	89.525	14:18:22	20-Sep-90	-23	KAmps	
N	26.085	W	80.423	14:18:22	20-Sep-90	-19	KAmps	
N	35.279	W	102.594	14:18:13	20-Sep-90	-21	KAmps	
N	26.092	W	80.422	14:18:23	20-Sep-90	-7	KAmps	
N	26.025	W	79.635	14:18:25	20-Sep-90	-21	KAmps	
N	26.009	W	79.613	14:18:25	20-Sep-90	-30	KAmps	
N	26.046	W	79.662	14:18:25	20-Sep-90	-108	KAmps	
N	25.994	W	80.728	14:18:28	20-Sep-90	-19	KAmps	
N	33.266	W	92.887	14:18:33	20-Sep-90	-46	KAmps	
N	33.265	W	92.886	14:18:33	20-Sep-90	-21	KAmps	Three strokes in one flash.
N	33.267	W	92.887	14:18:33	20-Sep-90	-21	KAmps	
N	35.519	W	102.018	14:18:21	20-Sep-90	-27	KAmps	
N	26.018	W	80.717	14:18:32	20-Sep-90	-33	KAmps	
N	26.059	W	80.713	14:18:32	20-Sep-90	-19	KAmps	
N	26.065	W	80.646	14:18:32	20-Sep-90	+7	KAmps	
N	26.050	W	80.713	14:18:32	20-Sep-90	-28	KAmps	
N	26.076	W	80.758	14:18:39	20-Sep-90	-49	KAmps	
N	25.519	W	80.654	14:18:39	20-Sep-90	-8	KAmps	
N	26.067	W	80.745	14:18:39	20-Sep-90	-7	KAmps	
N	26.064	W	80.746	14:18:39	20-Sep-90	-9	KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90	-35	KAmps	
N	26.577	W	80.242	14:18:44	20-Sep-90	-79	KAmps	
N	26.577	W	80.244	14:18:44	20-Sep-90	-19	KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90	-18	KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90	-49	KAmps	Eight strokes in one flash.
N	26.577	W	80.243	14:18:44	20-Sep-90	-44	KAmps	
N	26.578	W	80.244	14:18:44	20-Sep-90	-24	KAmps	
N	26.578	W	80.242	14:18:44	20-Sep-90	-12	KAmps	
N	26.576	W	80.242	14:18:44	20-Sep-90	-27	KAmps	
N	40.010	W	96.178	14:18:50	20-Sep-90	-31	KAmps	
N	35.885	W	92.639	14:18:50	20-Sep-90	+76	KAmps	
N	35.643	W	92.496	14:18:50	20-Sep-90	+108	KAmps	
N	35.576	W	92.494	14:18:51	20-Sep-90	-12	KAmps	
N	26.095	W	80.763	14:18:50	20-Sep-90	-26	KAmps	
N	33.260	W	92.879	14:19:05	20-Sep-90	-14	KAmps	
N	26.101	W	80.730	14:19:06	20-Sep-90	-52	KAmps	
N	39.974	W	96.141	14:19:07	20-Sep-90	+13	KAmps	
N	29.325	W	89.505	14:19:09	20-Sep-90	-27	KAmps	
N	26.096	W	80.491	14:19:09	20-Sep-90	-20	KAmps	
N	36.292	W	106.569	14:18:57	20-Sep-90	-32	KAmps	
N	26.015	W	80.740	14:19:11	20-Sep-90	+11	KAmps	
N	39.972	W	96.118	14:19:17	20-Sep-90	-43	KAmps	
N	26.047	W	80.724	14:19:16	20-Sep-90	-46	KAmps	
N	26.076	W	80.754	14:19:16	20-Sep-90	-41	KAmps	

Figure 1

TYPICAL ELECTRIC FIELD MILL DATA
DURING LIGHTNING ACTIVITY

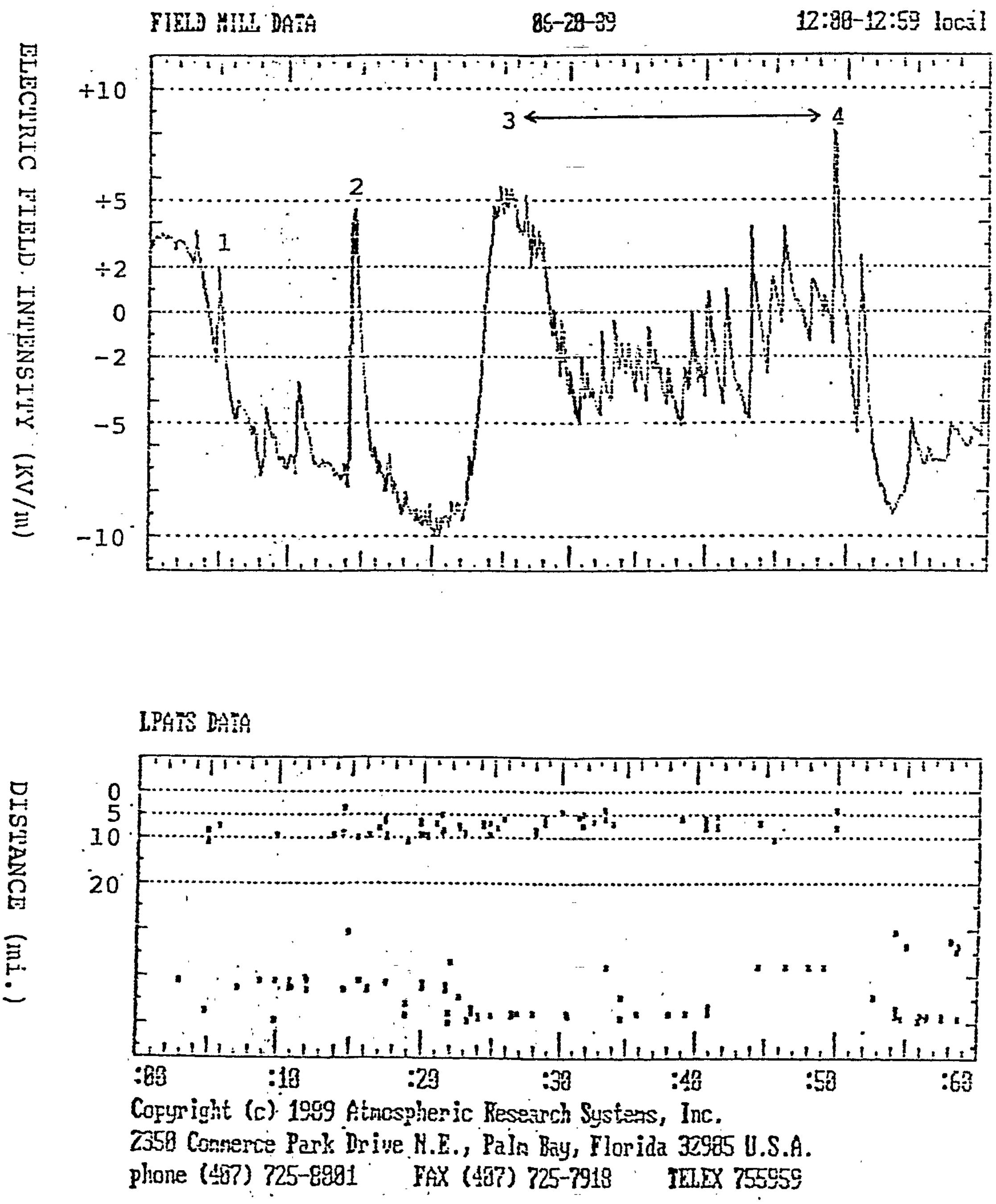

FIGURE 2.

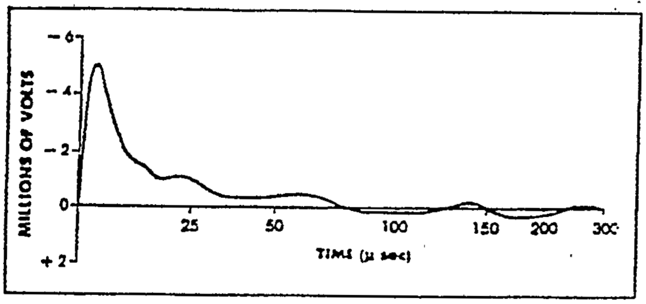

Figure 3. Cathode-ray oscillogram of highest voltage on a transmission line; 110 kV wood pole of Arkansas Power and Light Company; no ground wire.

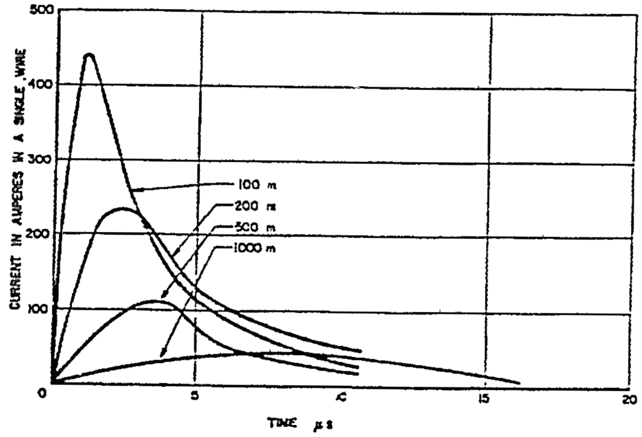

Figure 4. Current induced by a lightning stroke with a crest current of 150 kA and waveform of 5/65 μs at various distances from a line.

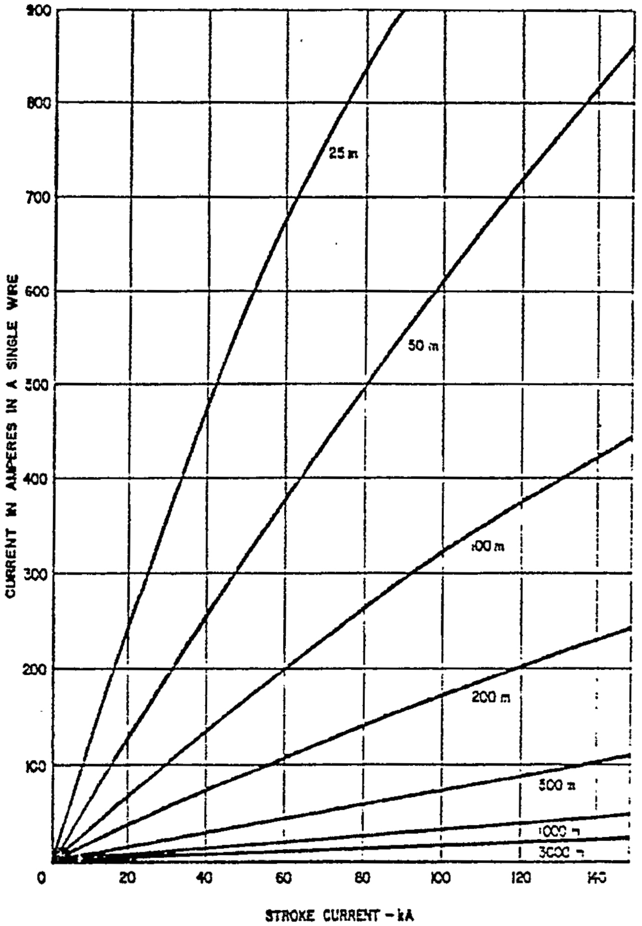

Figure 5. Current to earth at the ends of a single horizontal wire for various crest stroke currents and separating distances (zero soil resistivity).

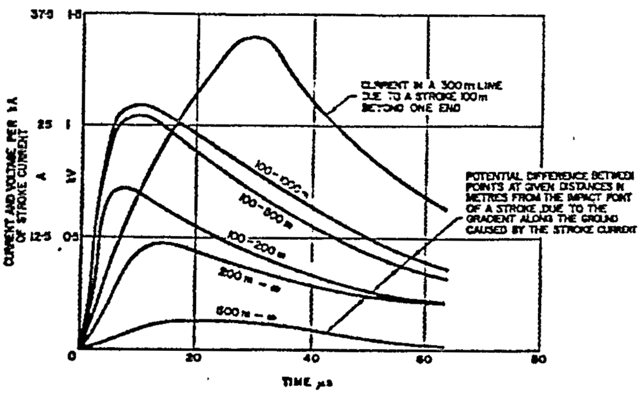

Figure 6. Voltages and currents in a horizontal conductor due to earth gradients arising from a finite each condicutivity. Ground resistivity 1,000 ohms/meter and stroke velocity 50 m μs^{-1}.

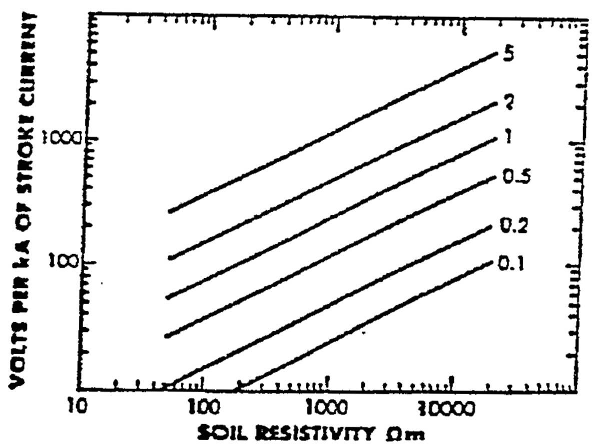

Figure 7. Crest voltage between the metal sheath and conductors at the end of the cable (the entry point of a lightning surge with a 5/65 μs waveform) for values of a sheath resistance between 0.1 and 5 ohms/kilometer $^{-1}$.

AUTOMATIC AIRPORT LIGHTNING ALERT SYSTEM

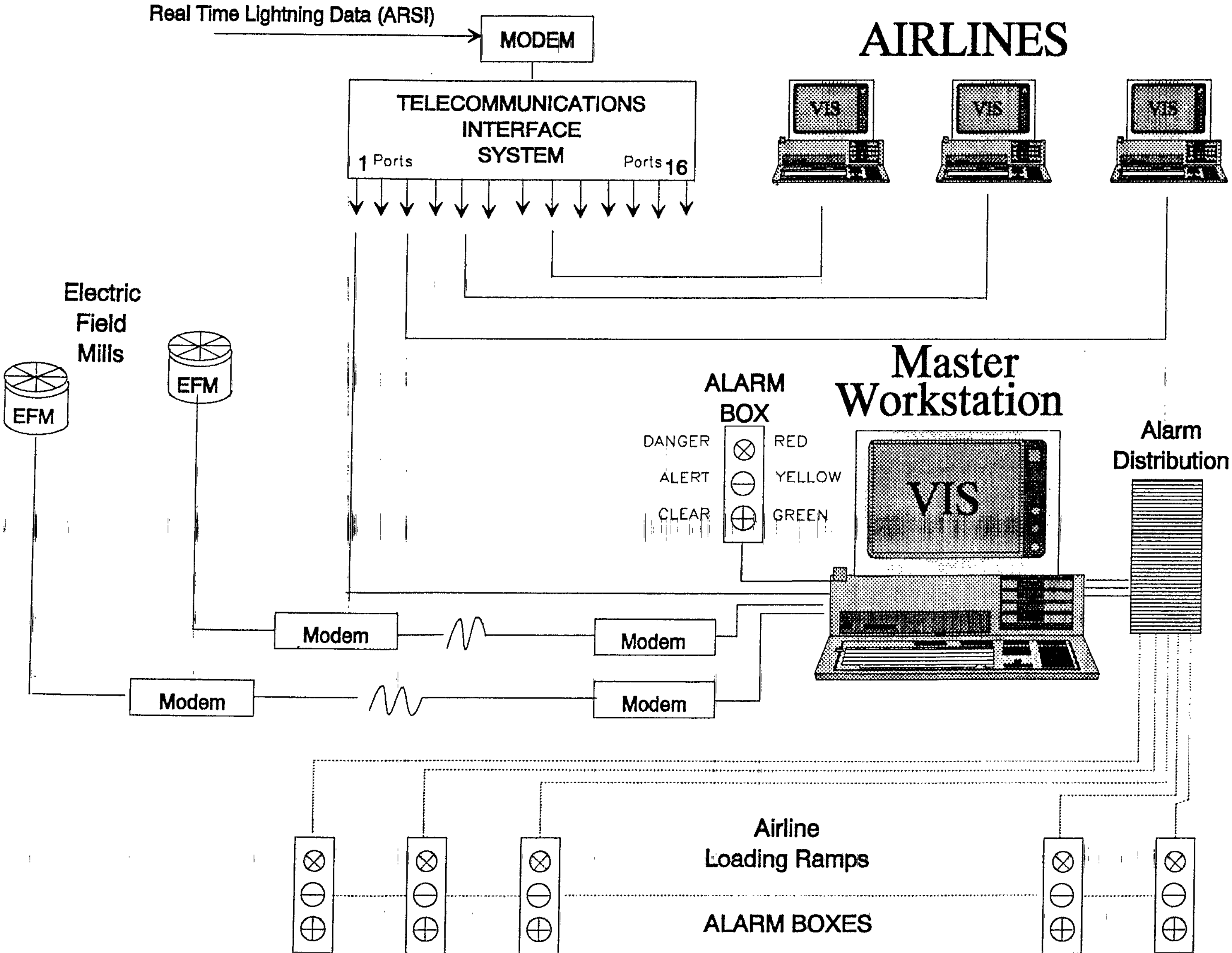

FIGURE 8